

Willis's sources on gothic vault construction

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Willis's article "On the construction of the vaults of the Middle Ages" marked a turning point in the study of Gothic vaults. It is still today the best exposition of the topic, a work to be studied with care by anyone wishing to know in depth how the cross-vaults of the Middle Ages were traced and built. Indeed, the word "construction" has the two meanings: we "construct" (trace) a curve, say, an oval with compass and rule, and we "construct" (build) an oval arch made of stone voussoirs with hammer and chisel on a centering.

The article has been cited many times; the splendid plates copied once and again. However, it seems that not many authors have dwelled in depth in its approach and content. It was cited, of course, in the fundamental work by Paul Frankl *The Gothic* (1960). But Pevsner (1970) in his monograph on Willis remarked that Frankl's book though an "invaluable study on the history of writings on Gothic architecture" was "weak on Willis". Pevsner didn't enter in the details of an "analysis [which] involved substantial technical and geometrical insights"; however, he qualified it as a "fascinating paper" and reproduced, for the first time in many decades, one of the plates.

Middleton's long paper of 1962 on "The Abbé de Cordemoy and the Graeco-Gothic Ideal" completes Frankl's book, going into the details of the "Survival of Gothic" and studying "the rational interpretation of Gothic" in France, previous to Viollet-le-Duc. Middleton studies in this context the technical handbooks by De l'Orme, Frézier and others. Middleton does not even mention Robert Willis. However, Willis's work was known to Viollet-le-Duc, who drew extensively on Willis's paper for the article "Voûte" in his *Dictionnaire* (1854) (see also, Prof. Girón's essay in this book).

It was Alexandrina Buchanan in her dissertation of 1994, “Robert Willis and the Rise of Architectural History” who made the first thorough study of Willis’s paper. In particular, Chapter 2 on “Vaults of the Middle Ages” discusses the paper in depth within the context of previous and contemporary English authors, and did extensive use of the original Willis papers in the Cambridge University Library (an impressive set of 32 vols, 10 box-files, 10 files and one bundle, which she catalogued for the CUL). Eventually, Buchanan’s book of 2013, *Robert Willis and the Foundation of Architectural History*, is the definite work on Robert Willis.

The aim of the present paper is modest. It could be seen as a series of footnotes to Frankl’s, Pevsner’s or Buchanan’s works, or to some of the more wide contributions contained in this volume. My objective is to describe the background against which the contribution of Willis should be judged. I will consider, then, the precedents concerning the tracing and construction of Medieval vaults as they appear in the sources cited by Willis himself in his paper.

Willis’s aims

Willis work begins with an “Introduction” where he first made a review of the literature which contained information about gothic vaults. The list is not long and will be examined later. The conclusion was that there were no documents of the period covering the origin and development of high Gothic; this was true in 1842 and it is still true today. The only source of information were the buildings themselves. The main aim of his study is formulated clearly by Willis: “It becomes, therefore, a curious and interesting subject of inquiry to trace, from an examination of the structures themselves, what geometrical methods were really employed in setting out the work, and how the necessity for these methods gradually arose” (Willis 1842, 2).

Willis had not merely an antiquarian (historical) interest; at a time were the fascination for gothic led to build in this Style he wanted not merely to “copy” but to “design” following the fundamental principles: “we shall never succeed in obtaining the master key to their [gothic] principles, and instead of *designing* works in the style of any required age, we must content ourselves with merely *copying* them. [Willis’s emphasis]

Willis discusses then the difficulties of the task: “For it will appear, as we proceed, that most of the facts required are of such a nature that they can only be derived from the existing buildings by the aid of scaffolding, minute measurement, and close observation, which it is not often in the power of mere travelling observers to obtain” (3), and expresses his hope the members of Institute of British Architects (the origin of the paper was a Lecture delivered in the Institute in July

1841) would contribute gathering facts. Unfortunately Willis's appeal was not followed neither for the members of the Institute nor for the next generations of gothic scholars.

Willis's sources

In his Introduction Willis cites a number of French and English treatises which contained information about medieval vaults. From France, he cites De l'Orme (1568 [1567]), Jousse (1642), Derand (1643), Desargues (1643), De la Rue (1728), Frézier (1738), and Jousse (1627) on carpentry. From Britain he only cites Halfpenny (1725) and Nicholson "whose various works on this subject are too well known to professional men to need enumeration". The French list is fairly complete; the English, succinct.

Along the paper he cites some other sources. The English translation by Whewell of Lassaulx (1829), "Mode of erecting light vaults over churches" published in 1831. Then, Ware (1822) *Tracts on vaults and bridges*. Two works by Nicholson: the *Builder's Director* (new edit. 1834) and the *Treatise on Masonry and Stonecutting* (1828). His own *Remarks* (1835) are cited twice. Then, several examples are cited from Pugin's *Specimens* and *Examples* which include the geometry of the wall ribs and cross ribs; also brief references to other historical works.

In all, the amount of references is small in comparison to the contemporary literature on gothic. As Willis states explicitly at the conclusion of his paper: "the methods which I have explained in this paper have been for the most part elicited from an examination of the existing vaults".

The method followed by Willis have been denominated "scientific": first, data are collected, and, then, a theory is formulated. However, what is often ignored is that a mere collection of data does not led to a "theory". As Darwin stated: "Without the making of theories, I am convinced there would be no observation" (letter to Charles Lyell, June 1860).

The basic assumptions of Willis are already contained in De l'Orme, Derand and Frézier. The plan of the ribs is the generator of the spatial vault. The ribs are arcs of circles or composed by arcs of circles. The precise curve of the ribs is determined by geometrical conditions: the profile of the liernes, the height of the bosses, the position of the centres, etc. The tas-de-charge is the necessary springing of the ribs and is produced by the intersection of the rib sections (templates). The rib skeleton is first constructed and, then, the webs fill the spaces between the ribs. These assumptions would have been considered obvious by contemporary French antiquarians, architects or engineers (tough they didn't mentioned them at the time) and were employed later by Viollet-le-Duc. The study of the

English treatises shows how much false premises could “blind” the observer. In fact, we could only “see” (understand) what we are able to see within a certain framework of knowledge. To think “against” a dominant framework is an extraordinary difficult exercise.

Willis did this, but he went much further. Measuring and analysing not a great number of vaults he was able to understand the great subtleties which may be hidden behind such evident and straight forward assumptions. Could it have been otherwise? Is gothic vaulting not an extremely refined art?

French authors: De l’Orme, Derand, Frézier

The main source of Willis is Philibert De l’Orme (1510?–1570). In his *Premier tome de l’architecture* (1567; reprint 1568), De l’Orme dedicated three chapters to the cross vaults which he called “voûtes modernes” or “croissée d’ogives”. In the first chapter (Chapter VIII), he explained the construction of a typical cross vault. He begins with a kind of apology: these vaults are no longer built by architects who know the true architecture (“la vrye architecture”), however they have been found to be very good (“esté trouvées fort belles”).

Then, De l’Orme describes a vault over an square plan with its “montée” (elevation of the ribs), Figure 1 (a). The exposition is systematic. First, he describes the plan of the vault, naming the different ribs (“branches”) and locating them in the plan with capital letters: the diagonal arches *B* (“croisée d’ogives”), the transverse arches *E* (“arcs doubleaux”), the “tiercerons” *T*, the “liernes” *C* and wall ribs *D* (“formerets”). The central boss is marked *A* and the secondary bosses *H*. The sections templates of the ribs (“les petites moules des ogives”) are *I*. (Willis incorporated the terms “lierne” and “tierceron” to the English nomenclature of gothic vaults.) Then, De l’Orme describes briefly an essential part of the vaults: the “tas-de-charge” (term which also has found a place in English language), formed by the first stones which receive the springings of the ribs, “ce sont les premieres pierres que on voit sur les angles, et mostrent le commencement et la naissance des branches”. Willis in his *Nomenclature* defined it as “The solid block of masonry which projects from the wall, and upon which the ribs rest” (Willis, 1844, 44).

On the left top of the drawing the profiles of the ribs are drawn: *O* the diagonal arches, *T* the tiercerons, *E* the wall and transverse arches, and *S* (on the right) the liernes. De l’Orme do not explain in detail how to trace these arcs of circumference. He only says that with a compass, and beginning, with the diagonals, it is possible to know them from the projection in the plan. De l’Orme explains that *AF*, the demi-diagonal of the plan, is the radius of the diagonal arch *O* in the elevation. But gives no more indications as how to obtain the rest of the arcs, just saying that the

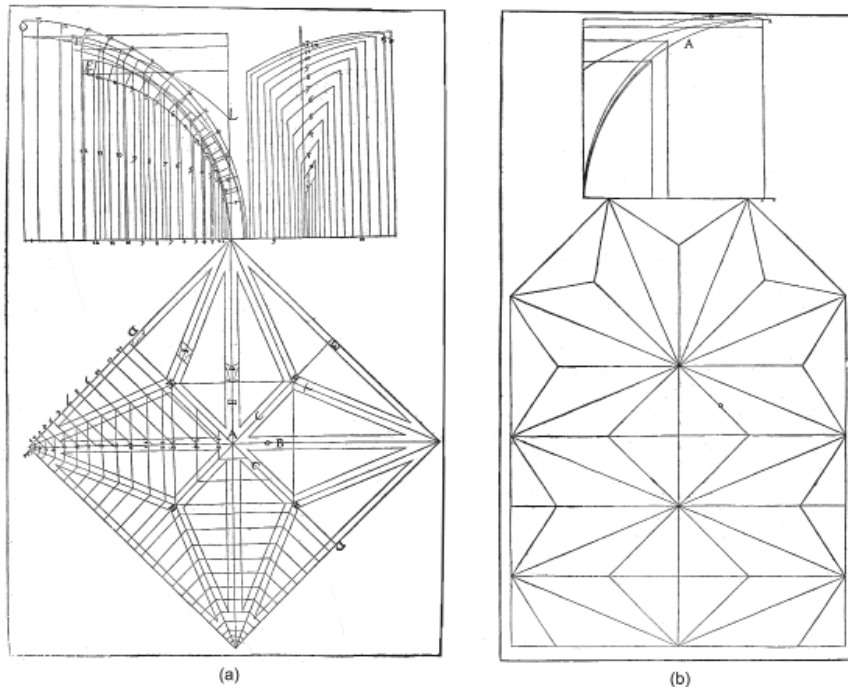


Figure 1

(a) Plan and rib elevation ("montée") of a cross vault (De l'Orme 1567, 108v); (b) Plan and rib elevation of church vault ((De l'Orme 1567, 109v)

procedure will be the same, because, he says, these things could only be shown in the practice of building. See Figure 2, for an explanation of the procedure.

The right part of the drawing show the form of the webs above the ribs, which after De l'Orme is the most difficult part if they are made of ashlar masonry, with the stones perfectly cut to fit between them. He insists in the next chapter on this difficulty, remarking that in most cases they are built of soft stone or brick, "... la plus part des pendentifs de voutes d'églises, ne se font de pierre de taille ... pour la difficulté qui sy presente. Et de la vient que souvent on les fait de brique, ou de quelque pierre tendre de moilon" (109r). (But the medieval masons never considered this possibility: the essence of gothic construction is to avoid unnecessary work. This mere intention puts De l'Orme outside of the gothic tradition.)

In the next chapter (Chap. IX), De l'Orme gives the example of a gothic vault for a church, showing the church's head as a half octagon (Fig. 1(b)). The drawing seems to be a copy of an actual trace. The skeleton of ribs is represented in plan

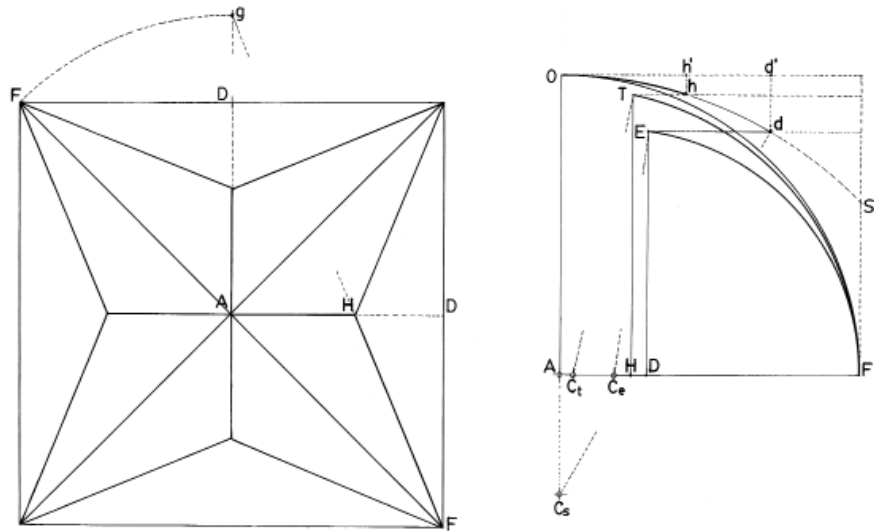


Figure 2

Exaplanation of Figure 1(a). Plan and elevation drawn separately. Procedure: 1) Draw the *diagonal rib*: arc FO with centre in A ; 2) draw the *wall/transverse rib*: locate point D (DF determined in the plan); either locate centre C_e (or fix the height DE) and trace the arc FE ; 3) draw the *lierne*: the lierne must pass through the keystone of the diagonal arch, O , and the keystone of the wall/transverse arch E ; then Od' in the elevation must be equal to DF in the plan; tracing the horizontal through E we obtain d . Trace the arc which passes through points O and d with centre in the vertical OA (centre C_s).

and elevation by lines. De l'Orme considers the vault of considerable strength due to the cross linking of the ribs, "la dicte voute sera forte pour les branches qui y sont entrelies, et s'entretiennent toutes ensemble, comme vous le voiez" (109). He remarks that it is not necessary to draw the thickness of the ribs, as the masons would know how to assign them ("les ouvriers les scauront bien faire").

Then, De l'Orme describes how to cut the joints among the stones. He probably refers both to the ribs and the masonry of the webs. The joints must concur to the centre; the intrados should be dressed smoothly, without visible irregularities, following always the circle lines of the elevation: "... les couches des lits de la maçonnerie soient toujours faictes par lignes droictes, et qui proviennent du centre don't est tirée la montée, et que les branches soient conduictes à droite ligne, et par le dessous avec leurs cyntres, sans que leur circonference face aucun jarret ... Mais il ne fault oublier que le tout *doit estre conduict suyvant la circonference du compas*". [my emphasis]

The thickness of the joints (“conmissures”) should be as thin as possible so that it would not be necessary to use wooden wedges between the stones. Also, the joints being thin, it is unnecessary to use much mortar, but only to grout with fluid mortar (“laictance”): “Sur tout il fault user des plus petites conmissures qu’on pourra, a fin qu’il n’y faille de grandes escailles, qui sont morceaux de bois qu’on met entre les ioincts. Il ne fault aussi y employer grand mortier, ains seulement les abrever de laictance, qui est la graisse de la chaux, ressemblant à du lait, don’t elle prend le nom.”

Examining De l’Orme’s drawings it is not difficult to find the essential assumptions. First, as we have seen, all the ribs *OF* (diagonal), *TF* (tiercerons) and *EF* (wall and transverse ribs) have a vertical tangent, so that the centre must be in the impost line. Second, and this is not so evident, the arc of the liernes *S* pass through the central boss *O* and the keystone *E* of the wall and transverse ribs (see Figure 1). Thirdly, once defined the position of *E*, it is possible to find the centre of arc *L* and, afterwards, to project the secondary boss *H* on it, obtaining the height *T* of the arc of the tierceron. Steps two and three could be reversed: instead of defining the height of the wall and transverse arches, we could decide first the profile of the liernes, selecting arbitrarily the center on the vertical passing through *O* in the elevation, or, as it occurs many times, deciding that the liernes are horizontal. Or it may be that the liernes *AH* are curve and the points *H* and *E* have the same height, which is also not uncommon. The practice have been resumed in Figure 2, where the elevation of the ribs have been drawn separately.

The “method of projection”

Willis cites another book by De l’Orme, his *Nouvelles Inventions* published in 1561 (Willis used the 1578 edition). There it appears published for the first time a method to trace surbased arches from a semicircular arch. De L’Orme called this arches “cherches rallongées”, which may be translated freely as “stretched” or “lengthened” arches or centerings, and which Willis named “the method of projection”. (The method had probably great diffusion in late-gothic in all Europe as there are 16th Century examples in Spain, France, Germany and Italy. It was first published by Albrecht Dürer in his *Unterweisung der Messung* (1525).) Willis cites also the stone-cutting treatise by Jousse (1642). Jousse employed the expression “courbe rallongée” also, and as Willis remarks, “The fact of this problem having a familiar name shows that it was of common use amongst workmen.” The same procedure appears, as we shall see, also in the the carpentry treatise of the same author published earlier (Jousse 1627).

From a geometric point of view it is indeed a method of projection. However, it is doubtful that the medieval stone masons used it with this awareness: proba-

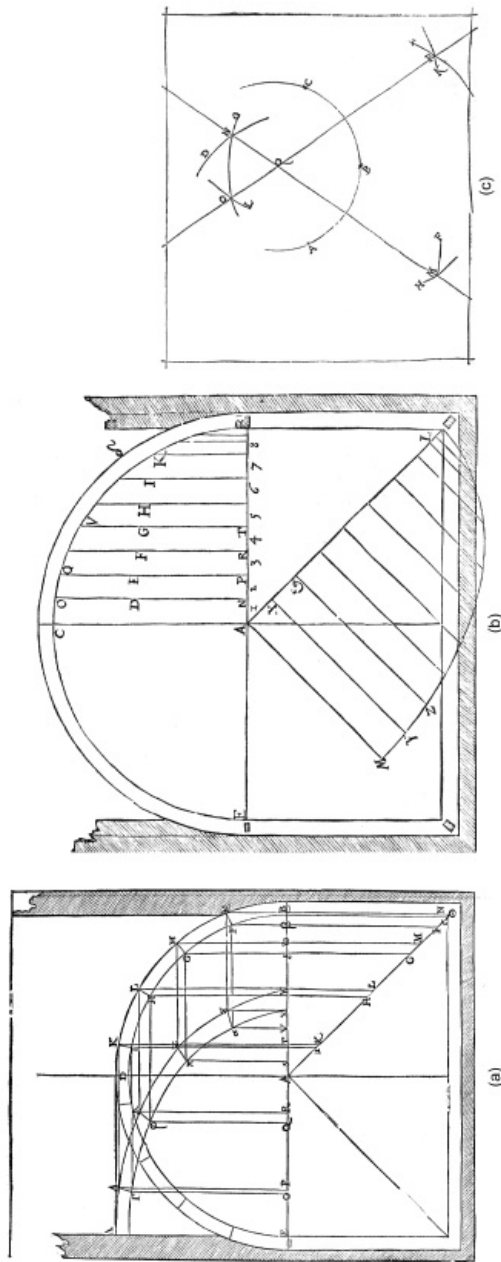


Figure 3

Lengthened arch: (a) and (b) Two methods to draw a "cherche rallongée" for the ridge of a square cloister vault; (c) Method to find "les trois points perdus". (De L'Orme 1561)

bly it was a “receipt”, a procedure composed of several steps which leads to the desired result. As we shall see, English architects and carpenters of the 18th Century employed it widely.

De L’Orme used two different representations of the method, applied in both cases, to a vault in “cul-de-four” (a cloister vault), Figure 3 (a) and (b). In both methods the generating arch, the section through the middle of the cloister vault, is divided into a number of parts. Vertical lines are traced which cut the horizontal line AB and the diagonal AO , giving the vertical and horizontal coordinates of the points of the stretched arch. In the first method, Fig. 3 (a), the arch is drawn on the springing line; in the second, Fig. 3 (b), on the diagonal.

The curve obtained is an ellipse, which has a varying radius of curvature. For a stone mason this would have been a problem, because he needs geometric templates for each voussoir: in the ellipse each voussoir of a demi-arch will need a different template. But, ¿what would be the radius for each one?

De L’Orme teaches the reader how to do this in a chapter entitled “Maniere de trouver les trois pointz perdus pour s’en aider à faire les cherches r’allongées” (Way to find the ‘three lost points’ to help to trace the stretched arches), Figure 3 (c). The construction is evident for the modern reader: tracing arches with the compass from the three “lost” points A, B, C , we trace perpendicular lines to segments AB and BC , and the point of intersection Q is the centre of the circumference passing through the three points (which are no longer “lost”).

De L’Orme instructs us to take each three points in turn, to obtain an smooth curve (“sans qu’il y ayt iarret”). However, as every circumference would have different radius, with a different centre, it is not clear at all how would it be possible to avoid discontinuities. I have found the key to the procedure in another drawing from the carpentry treatise by Jousse (1627), Figure 4 (a). Once obtained the “lost” points of the new curve, $I, 2, \dots, 9, D$ in Figure 4 (b), we trace perpendicular lines to each of the segments between the points ($9''$, $8''$, etc.). The intersection of $9''$ with $8''$ gives D' ; from this centre we trace the arc $D8''$ to the first point of tangency. Then, with centre in $9''$, passing through 9 , to the next point of tangency, and so on.

In this way we obtain a polycentric “smooth” curve, a precedent of the curves employed in the 18th and 19th for surbased arches in the bridges. The procedure must have been tedious for the masons or carpenters, but de L’Orme (and Jousse) wanted to obtain an exact template for every voussoir (piece of wood).

Derand, Frézier

François Derand (1591–1644) was the next French author to dedicate some attention to gothic vaults. In his *L’architecture des voûtes* (1643) he gives a de-

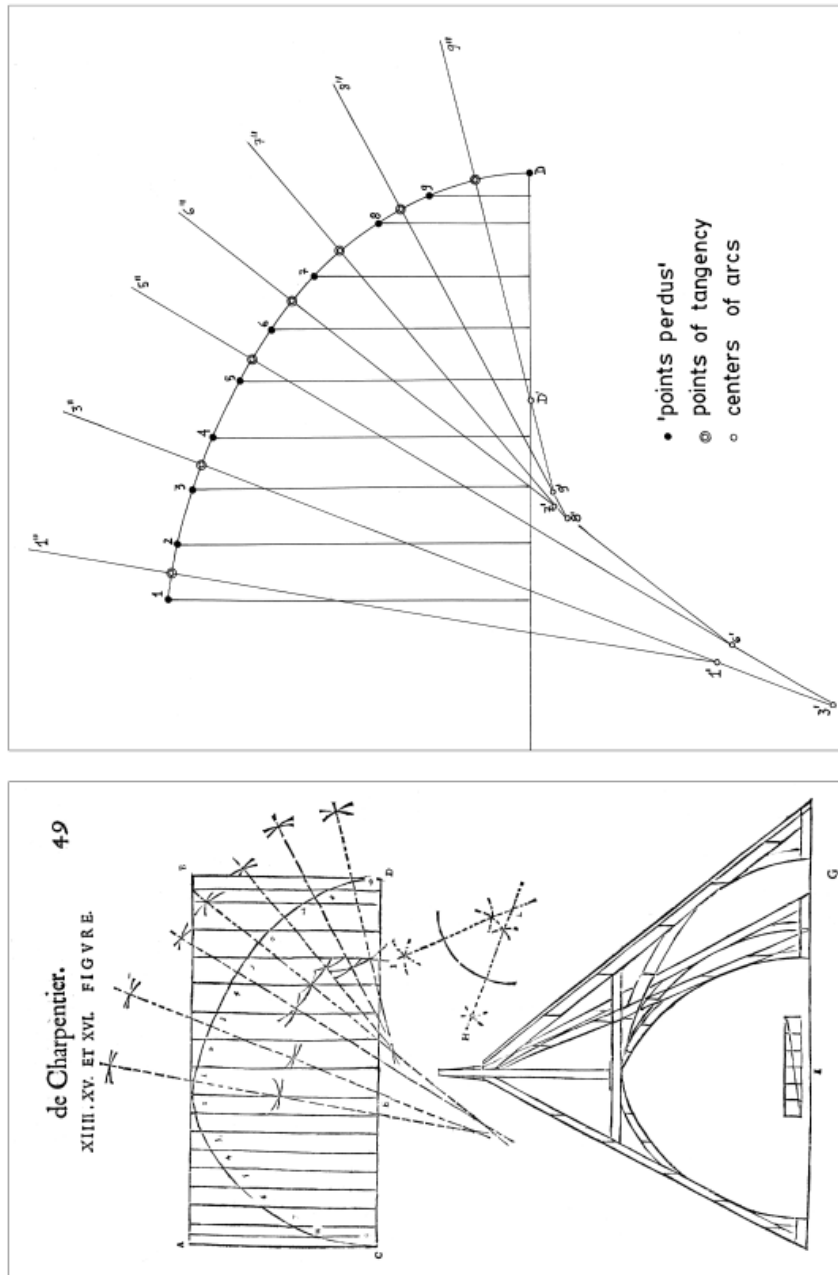


Figure 4
 (a) Plate from Jousse (1627, 49), showing the method to draw the “courbes rallongées” for the design of trusses; (b) explanation of previous figure

scription based in De l'Orme. The plan is the same and so is the method to obtain the radii of the ribs, which are also drawn separately, Figure 5 (a). There are some differences which show the different date of publication: for example, Derand considers the possibility of forming a wall or transverse rib with a semicircular stilted profile (and this was criticised sharply by Frézier). But, in essence, the procedure is the same.

However, his comments about the construction of the *tas-de-charge* are most pertinent (Derand do not use the term "*tas-de-charge*" for gothic vaults). To him, this is also the most difficult part, as there concur the different ribs in an small space where they interpenetrate. Besides, in elevation, each rib moves with a different radius and different direction and, as a consequence, some are seen entirely and other only in part, and only the practice would permit to understand the problem: ". . . comme on vient à les élever, les uns prennent leur contour d'un costé, les autres de l'autre: quelques-uns paroissent entiers dès leur origine, quelques autres ne paroissent qu'en partie, d'autres ne se monstrent qu'à une certaine auteur, comme la pratique le fera mieux voir, que tous les discours que nous en pourrions faire icy." (Derand 1643, 394)

However, Derand tried afterwards to explain the procedure. First, the templates of the ribs should be placed in their position (on a horizontal plane), tracing then their contours and marking some with dotted lines, others continuous lines, or with ink or pencil of different colours, as is necessary to distinguish clearly in the plan which lines are free and protrude, and which lines remain embedded within the others: ". . . pour en venir plus facilement au bout, il faut que vous placiez sur le plan, au lieu où les dits nerfs se rencontrent, la forme et façon d'un chacun d'iceux, les y traçant fuivant la diverfe situation qu'ils y doivent avoir, marquant les, uns avec les lignes ponctuées, les autres avec lignes pleines, même vous servant d'ancre ou de crayon de diverfes couleurs, lorfque la multitude des dits nerfs l'exigera pour en mieux éviter la confusion: car ce faisant vous remarquerez plus aisément sur vostre plan, quelles parties d'iceux se trouveront libres et dégagées, et quelles envelopées les unes dans les autres." (395)

Next, considering the curvature of each rib it would be easy to ascertain, at which height some ribs begin to protrude and which are completely free: "Et tirant sur chacune d'icelles les cintres qu'elles doivent avoir, il vous fera facile de reconnoistre à quelle hauteur elles commenceront à paroistre, et à quelles elles se trouveront tout à fait dégagées".

Derand finish his exposition making some considerations about the sections of the ribs, and about the convenience of making templates of each one of them (ogives, arc doubleaux, tiercerons, formerets et liernes). After Derand, cross ribs and tiercerons should have the same thickness and form ("*moulure*") so that the meeting of both ribs at the boss would be more satisfactory ("*plus agreable*").

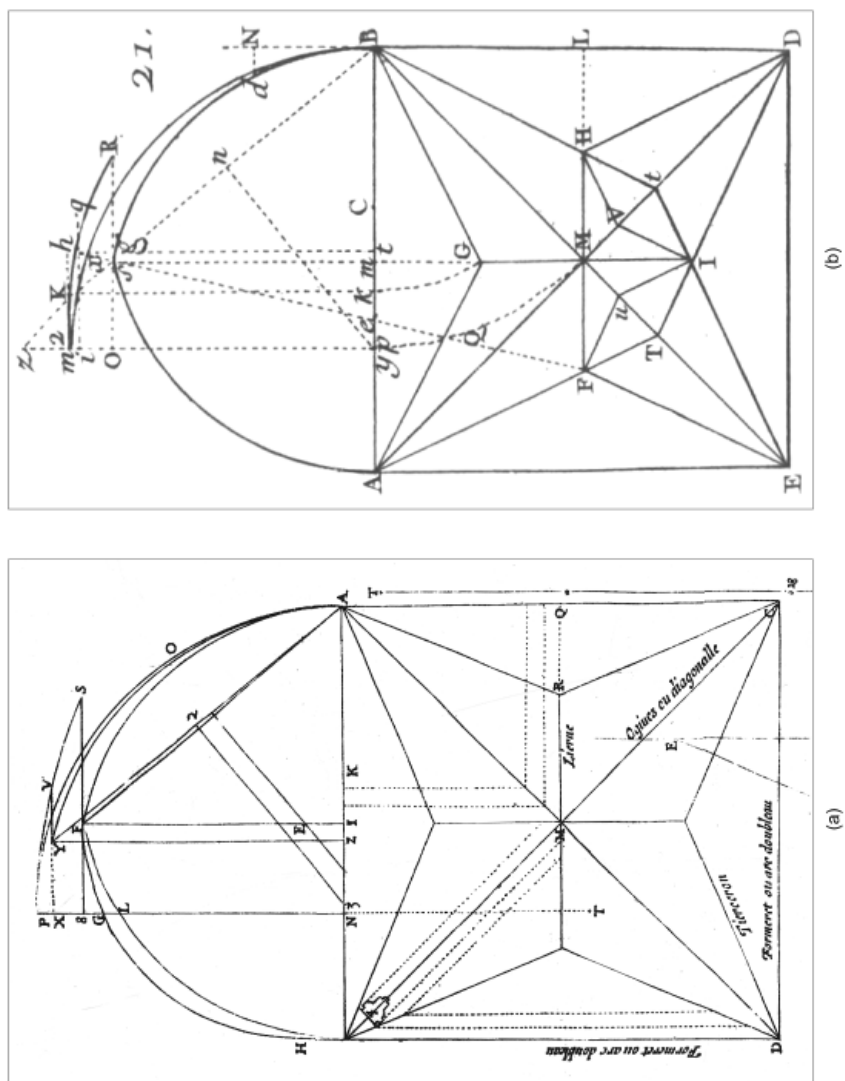


Figure 5
Tracing of a gothic vault: (a) Derand (1643, 377); (b) Frézier (1739, Pl. 71) (cf. Fig. 6)

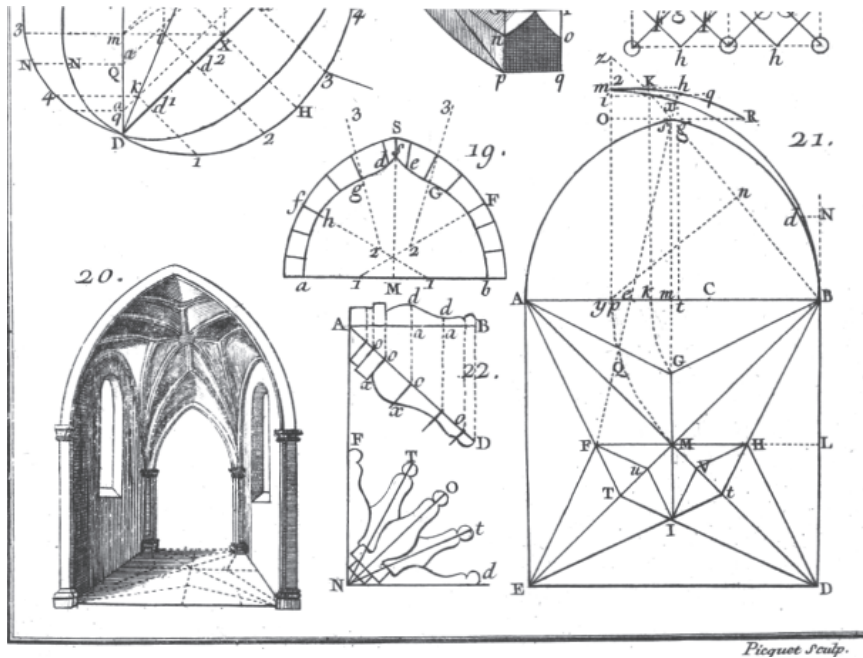


Figure 6

Frézier on gothic vaults. Note the sketch to explain the construction of the tas-de-charge, 22. in the plate (1739 III: Pl. 76)

Amédée François Frézier (1682–1773) published in 1737–39 his three volumes of his *La théorie et la pratique de la coupe de pierres*, the most important treatise on stereotomy ever written. He dedicates also some pages to gothic vaults. His comments about their advantages show a deep understanding of masonry construction and also a dislike to gothic forms, particularly to the pointed arches.

Frézier dedicates eight pages to the gothic vaults (“voutes d’arêtes gothiques”) in the third volume of his treatise (Frézier 1739, III: 24–31). Frézier justifies his discussion on grounds of the necessity of reconstructing some parts of them in the maintenance of existing buildings: “. . . mais comme dans les réparations des anciens Cloîtres, Eglises, ou autres Edifices, il se présente des occasions d’en rétablir quelques parties, il est nécessaire d’en connoître le Trait” (25). Frézier cites Derand, but not De l’Orme. The exposition is more systematic but the content is essentially the same. The same vault plan and the same way to trace the different ribs which appear drawn separately on the top, Figure 5 (b).

Frézier agrees with Derand that the most difficult parts in gothic building are the intersection and the springing (tas-de-chartge) of the ribs. For the intersections he considers convenient that all the ribs have the same section (“moulures égales”), again following Derand. As regards the springing or tas-de-charge (which he calls “cu-de-lamp”), he says it is necessary to make a projection as *N* in Figure 6 (22.), marking the directions of the ribs: *NF* the wall rib or “formeret”, *NT* the tierceron, *NO* the cross rib or “augive”, *Nt* the other tierceron, and *Nd* a transverse rib or “arc doubleaux”. He notes that the main ribs (*NF*, *NO*, *Nd*) cover the others. To know at which height the ribs become free it is necessary to look at the projection or salience of the ribs at different heights; for example considering *d* at height *BN* in Fig. 5 (b). Then, drawing again the sections of the ribs in plan for this height it is possible to know if all the ribs are free or are still covered by the main ribs. The explanation is incomplete and it is evident that Frézier is resuming a common practice among the workers, which was unearthed more than a century later by Willis.

English authors: Halfpenny, Ware, Nicholson

In the making of a theory it is important to be able to discard common beliefs. In England around 1800 circulated several methods to construct pointed arches and the “groins” (cross arches) of gothic vaults which were simply fanciful; so we will consider them nowadays. But the fact is that these methods have been published continuously for a century and formed part of the cultural background. First thing to conduct a research on gothic tracing methods was to get rid of them.

Halfpenny, Nicholson

It appears that these methods were introduced by William Halfpenny (–1755), carpenter by formation, who published numerous manuals (20 are cited in the *DNB*) on building, geometry, arithmetic, perspective, . . . and gothic and chinese architecture. Perhaps the more influential was his *Art of sound building* published in 1725.

Halfpenny’s offer no more than a collection of rules with two novelties, Figure 7: 1) he introduced a method to draw an arch by tangents, which may easily adapted to any form; 2) he made extensive use of the method of projection. But Halfpenny is an eclectic; he gives also the construction of pointed arches by arcs of circumference. In fact, The book is a collection of step-by-step rules, without any geometric explanation or inquiry on the nature of the curves involved. (This construction first appeared in France at the end of the 17th Century. It appears

that it was first published by La Hire (1702) who demonstrated that the curve is a parabola.)

Both methods were diffused in the English building manuals of the 18th Century (by Batty Langley, William Pain, Francis Price and others) and they appear still in the first half of the 19th Century. Willis was very critical to Halpenny “who, living at period when Gothic architecture had sunk into complete neglect, may very well be excused for having misapplied as he has done the projection system to the finding the ‘Mitre Arch of a Regular Groin when the Intersecting Arches are Gothick ones’” (Willis 1842, 22), Figure 7 (Fig. 22).

Willis cites also Peter Nicholson (1765–1844) author of numerous handbooks on building. Willis is particularly acid with Nicholson “who has also taken much trouble to construct a Gothic vault with *cuniconoidal surfaces* and upon other fanciful hypotheses, which, as they produce curves for the ribs totally different from the genuine ones, can answer no purpose but that of destroying the mediaeval character of the work”, Figure 8.

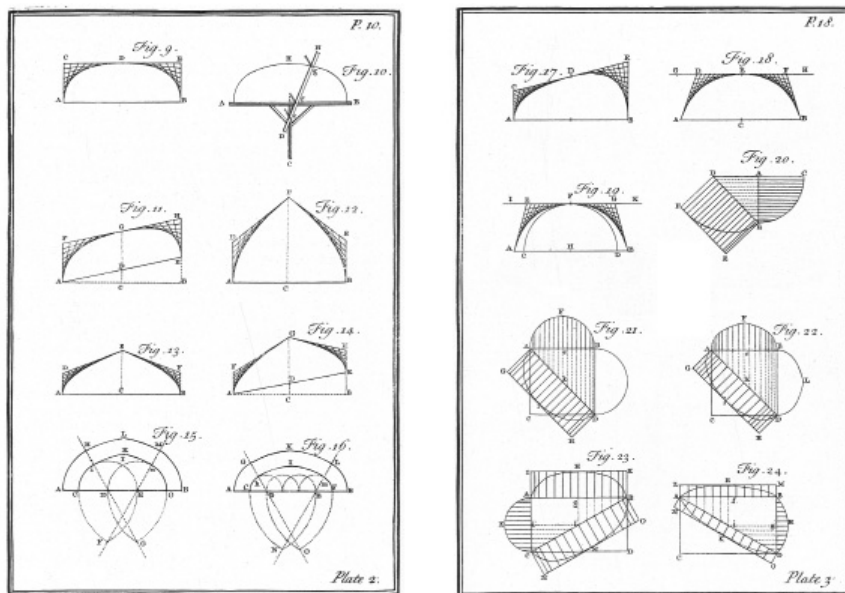


Figure 7
Plates from the *Art of sound building* (Halpenny 1725) showing the construction of arches and groins

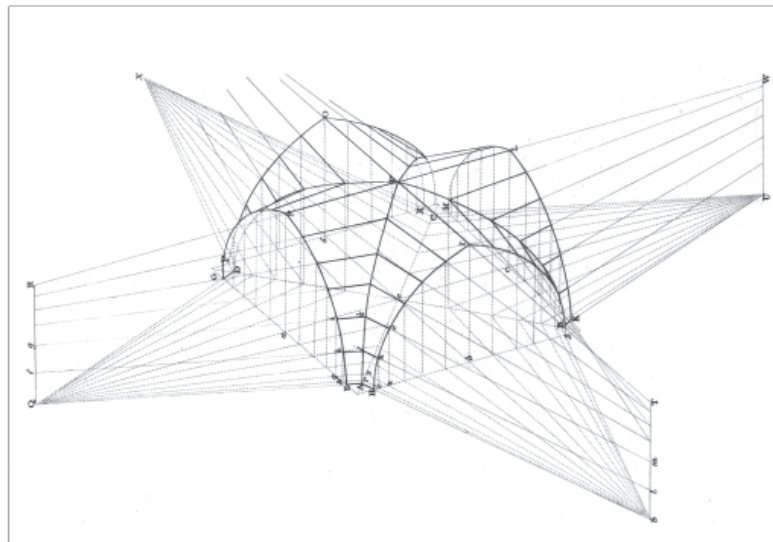
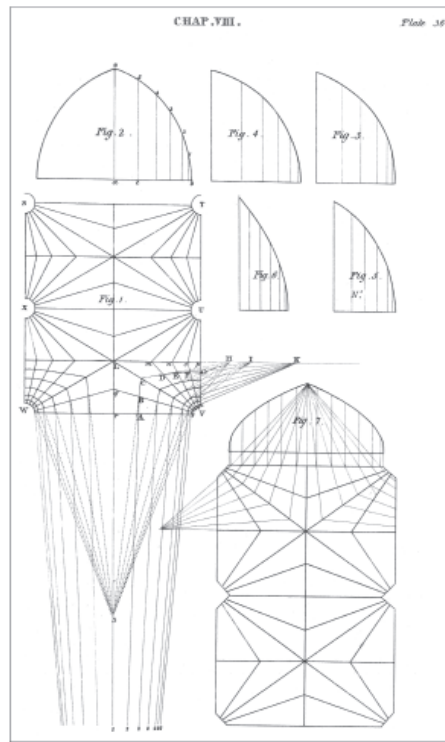


Figure 8
Gothic vault made of “cuniconoidal surfaces” after Nicholson (1828)

Pugin

Augustus Charles Pugin (1762–1832) made very accurate drawings of gothic vaults and buildings, which he published mainly in his *Specimens* (1821–23) and his *Examples* (1828–1831), with several reprints and editions. He collaborated with Britton and Le Keux in the *The Architectural Antiquities of Normandy* (1828) where he made detailed drawings of the churches in Caen. What was of interest to Willis were the detailed drawings of the vaults, in particular when Pugin draw the geometry of the ribs.

From the *Specimens* Willis quote two vaults. The first is a diagram of the vault on the east side of the cloisters at Westminster, Figure 9. The drawing shows all the ribs springing from the corner on the same line, the diagonal of the plan, instead of in a separate diagram as Philibert (Fig. 1) or Derand and Frézier (Fig. 5). But, making abstraction of this, the diagrams are evidently constructed on the same principles. Willis remarks that all the ribs have the same radius, “*the diagonal rib has the same radius as the transverse ribs*” (Willis 1842, 17) —which is nearly true, and omits saying that also the tiercerons have very nearly the same radius also. Willis was interested in the principle “of employing a common radius for the diagonal and transverse ribs [which] agrees with many other examples”.

In fact, Pugin was reinterpreting a drawing from Rondelet's *L'art de bâtir* (first edition, 1802–1817; probably the most popular building manual of the 19th Century.) Rondelet dedicates several pages in the second volume to the study of gothic vaults. Figure 10 shows the plan of a “*voûte gothique à triple âretes*” which correspond to the church of Saint Gervaise in Paris. The plan of the vault is square but is of the same type of the previous Westminster vault (upon a slightly rectangular plan). It is obvious that Rondelet was the source of Pugin's drawing though it is also evident that Pugin has studied and redrawn the plate. What effect produced this in Pugin? It is impossible to know, but it is a fact that only after this first volume of the *Specimens* Pugin began in a systematic manner to indicate the centres and curvatures of arches and vaults in his drawings, and his section of the church of St. Ouen in Caen, he measured and drew the cross arch of the lateral aisles (Britton 1828, Pl. 4).

The second drawing from Pugin cited by Willis, published in the second volume of the *Specimens* (1823), is from the vault of the Lady Chapel in St. Saviours, Southwark, Figure 11. It is a cross vault with horizontal ridges and what is remarkable is the constructive detail of the drawing. Indeed it was made by George Gwilt in 1822 during his work of restoration of the vaults (Gwilt 1857).

The profile of both the cross and transverse ribs are given. For the transverse rib he measured the height of the arc, considering it an arc of circumference, and then geometrically found the centre which is under the springing

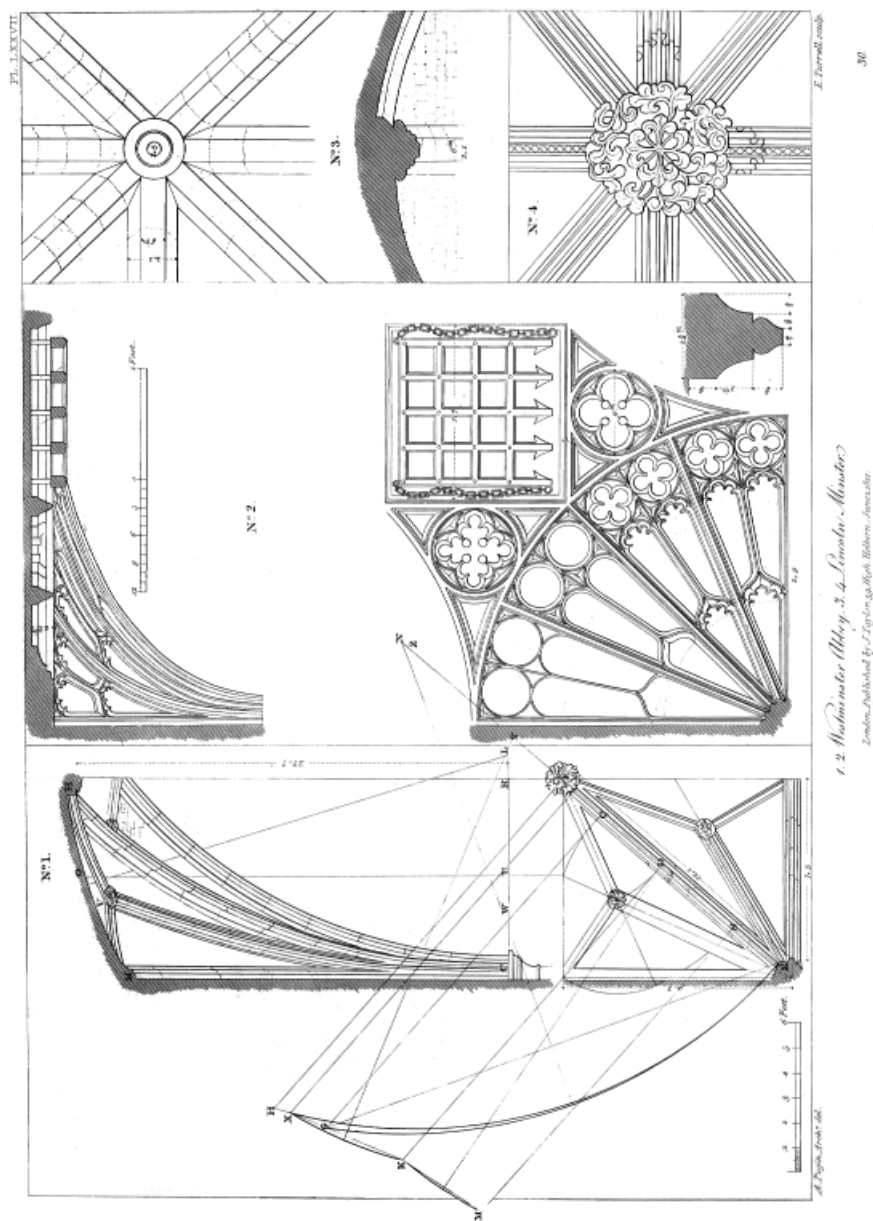


Figure 9
Vault on the east side of the cloisters, Westminster (Pugin 1821, *Specimens* vol. 1, pl. 77)

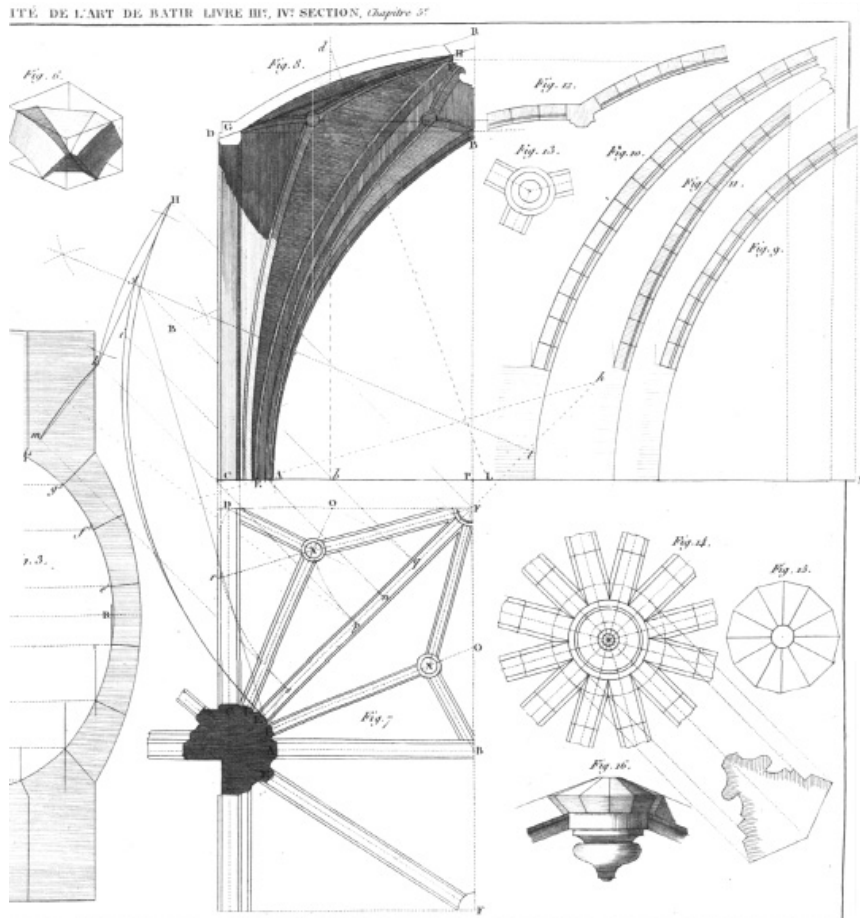


Figure 10

Vault of the church of St. Gervaise, Paris (Rondelet 1805 *L'art de bâtir*, vol 2, pl. 51)

line. The cross rib seems to have been surveyed from an scaffold, measuring vertical distances from the impost level. In any case, Gwilt drew a slightly surbated circular arch, with again the centre well below the impost plane. Pugin remarks, besides the curvature of the ribs the “inclination of the intermediate courses towards the centre of the groin” (Pugin 1823, 30). It is indeed an splendid constructive drawing.

Willis cites another two vaults from the *Examples*, published after 1828. There, throughout the whole work, Pugin interest in knowing the actual geome-

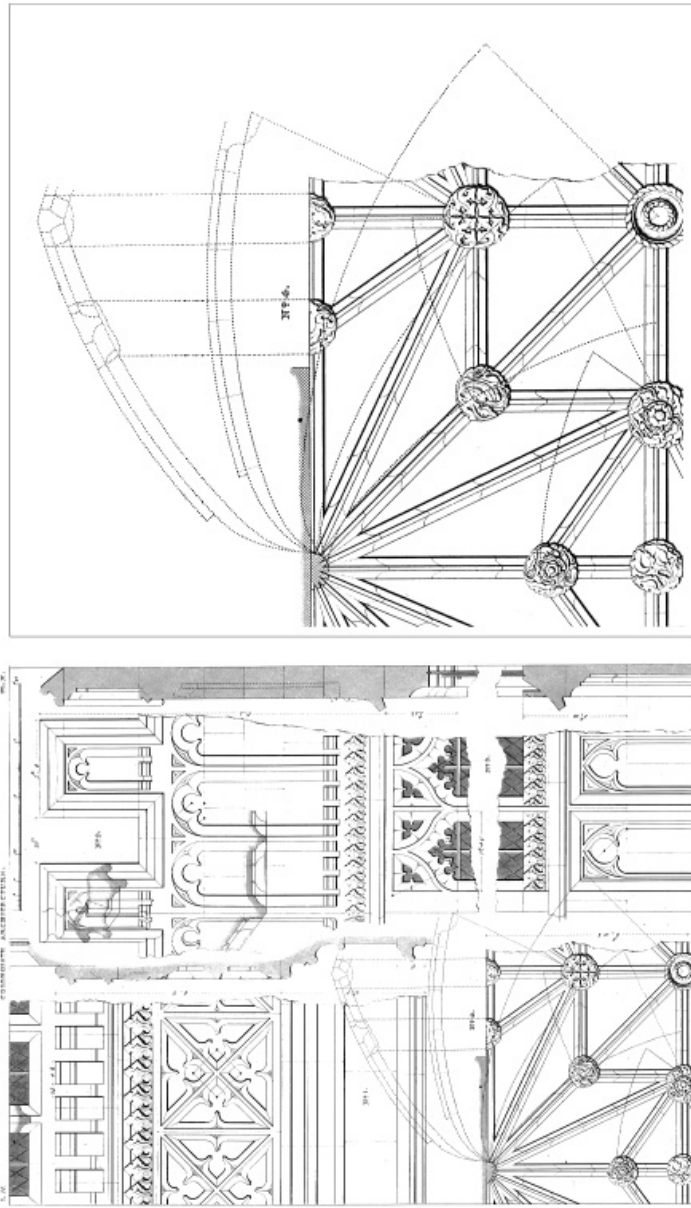


Figure 12

Gateway of Magdalene College, Oxford (Pugin 1831 *Examples* Vol. 1, Pl. 10). *Right*, enlarged view eliminating some lines to show the profile of the ribs

try of the curves of arches and groins is evident. Willis chose the most significant examples. In the gateway of Magdalene College (Oxford), Figure 12, “the ridge ribs are horizontal, and consequently the arches ribs all of the same height. Each rib consists of two arcs of circles, but the lower circle is of very small di-

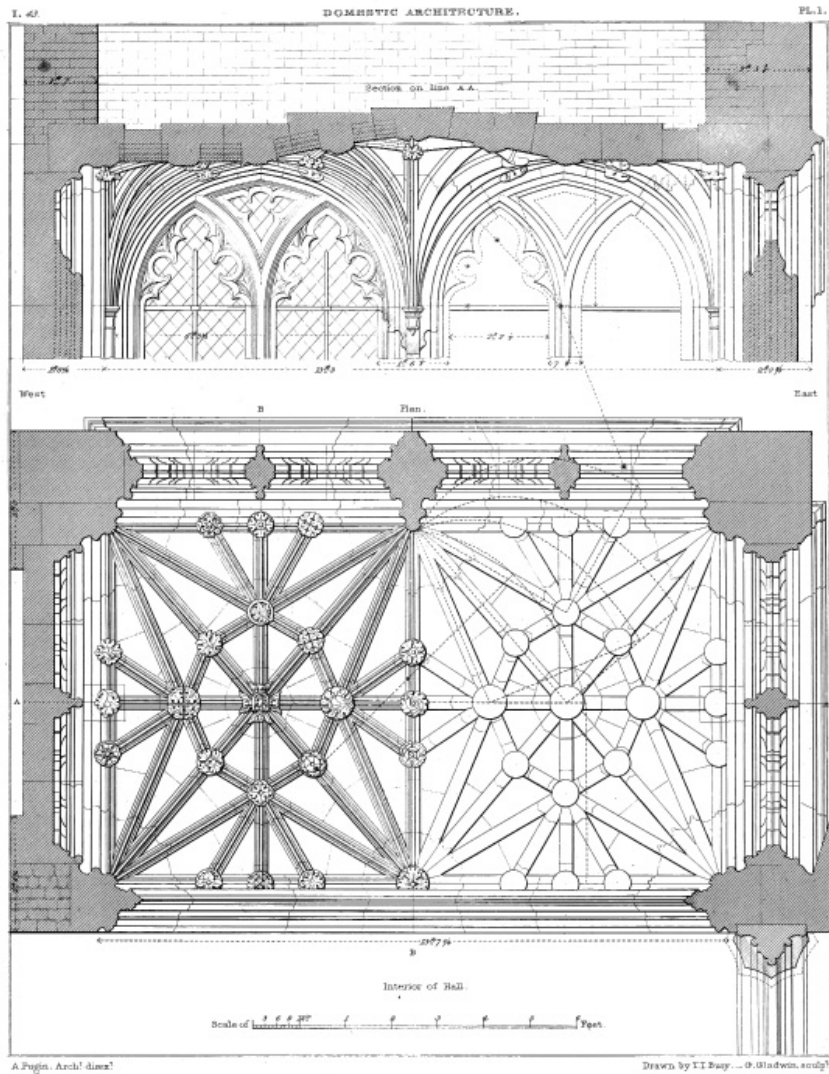


Figure 13
Vault over a bay window of Eltham Palace (Pugin 1831 *Examples* Vol. 1, Pl. 1)

ameter with respect to the upper circle, its radius being about one-ninth of the latter, and the same in all the ribs. All the upper circles of these ribs appear in this drawing to have the same radius, which is equal to the span of the transverse arch" (Willis 1842, 26).

The vault over a bay window of Eltham Palace, Figure 13, constitutes good example of study. "The ridge ribs are not horizontal, consequently in describing the curves of the arched ribs, the ridge ribs were probably first determined to give the heights of these ribs. Each rib, being half a four-centred arch, consists of two arcs of circles, the radius of the lower arc being a little less than half that of the upper arc, and this latter radius is again equal to the span of the smallest arch. These may be accidental proportions; however, the two radii are respectively the same in every rib, and consequently the different heights and spans are accommodated . . . by employing different proportional lengths of the two circles in each rib. The centre of the lower circle is in all placed on the impost level, and this I believe to be universal in four-centred arches" (27). In the plate Pugin only indicated the centres and radii of the wall ribs and of the mid-transverse rib. Again, it is evident that Willis studied the drawing with great care.

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